Ultrasonographic reference values for the deep branch of the radial nerve at the arcade of Frohse

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Abstract

Purpose The deep branch of the radial nerve (DBRN) enters the forearm as it passes under the arcade of Frohse. This is the most common entrapment site of the DBRN in the forearm. In this study, we investigated the ultrasonographic reference values for the diameters and cross-sectional area (CSA) of the DBRN at the level of the arcade of Frohse in a healthy sample of the population.

Methods Sixty-five healthy Caucasian volunteers (130 nerves) were recruited for this study. The reference range [mean $\pm$ 2 standard deviations (SD); 2.5th–97.5th quintiles] and the upper limit of the side-to-side difference were determined. The effects of age, gender, handedness, height, and body mass index were examined.

Results The mean age was 41.8 ± 11.2 years (range 18–75 years). The mean $\pm$ 2SD of the CSA was $0.50\text{--}1.42\text{ mm}^2$. The upper limit of the normal side-to-side difference was 0.35 mm^2 . The differences between males and females and between the dominant and non-dominant arms were not significant. The mean anteroposterior and transverse diameters were 0.83 ± 0.13 and 1.23 ± 0.29 mm, respectively. A significant correlation between the dominant-side CSA and age ($r=0.41$; $p<0.001$) was observed. The correlations between CSA and height ($r=0.19$; $p=0.12$) and body mass index ($r=0.22$; $p=0.07$) were not significant.

Conclusion The measurements obtained in this study are valuable for examining DBRN pathologies using high-frequency ultrasound. The findings showed that age was associated with the DBRN CSA, while gender, height, and body mass index were not.

Keywords Ultrasonography · Radial nerve · Reference values · Nerve compression syndromes

SOMMARIO

Scopo Il ramo profondo del nervo radiale (DBRN) entra nell'avambraccio passando sotto l'arcata di Frohse. Questo è il sito di intrappolamento più comune del DBRN nell'avambraccio. In questo studio abbiamo analizzato i valori di riferimento ecografici per il diametro e l'area della sezione trasversale (CSA) del DBRN a livello dell'arcata di Frohse in un campione di soggetti sani.

Metodi Sessantacinque volontari sani di razza caucasica (130 nervi) sono stati reclutati per questo studio. L'intervallo di riferimento (media $\pm$ 2 deviazioni standard (SD); 2,5° -97,5° quintili) e il limite superiore della differenza fra i due lati sono stati determinati. Gli effetti dell'età, del sesso, della dominanza della mano, della altezza e l'indice di massa corporea sono stati esaminati.

Risultati L'età media era $41,8 \pm 11,2$ anni (range: 18-75 anni). La media $\pm$ 2 DS di CSA era $0,50\text{--}1,42\text{ mm}^2$. Il limite superiore della normale differenza fra i due lati era $0,35\text{ mm}^2$. Le differenze tra maschi e femmine, e tra le braccia dominanti e non dominanti non erano significative. I diametri medi anteroposteriore e trasversale erano $0,83 \pm 0,13$ mm e $1,23 \pm 0,29$ mm, rispettivamente. Una correlazione significativa è stata osservata tra CSA dominante ed età ($r=0.41$; $p<0.001$). Le correlazioni tra CSA e altezza ($r=0,19$; $p=0,12$) e indice di massa corporea ($r=0,22$; $p=0,07$) non erano significative.

Conclusioni Le misurazioni ottenute in questo studio sono utili per eseguire valutazioni di patologie del DBRN tramite l'utilizzo di ultrasuoni ad alta frequenza. L'età ha mostrato una associazione con il DBRN CSA; mentre il sesso, l'altezza

e l'indice di massa corporea non erano significativamente associati.

Introduction

The deep branch of the radial nerve (DBRN), also known as the posterior interosseous nerve (PIN), originates from the main trunk of the radial nerve at the level of the lateral epicondyle of the humerus. The DBRN curves around the neck of the radius then passes under the tendinous arch of the superficial edge of the supinator muscle, an anatomical site that is commonly known as the arcade of Frohse. This nerve is mainly a motor branch and innervates the majority of the extensor muscles in the posterior compartment of the forearm [1, 2]. The arcade of Frohse is the most common entrapment site of the DBRN in the forearm [3, 4]. DBRN entrapment can result in a constellation of symptoms that is commonly referred to as “PIN syndrome (PINS),” “radial tunnel syndrome (RTS),” or “supinator syndrome.” The symptoms mainly include weakness of the wrist extensor muscles and deep pain in the lateral–dorsal proximal forearm [5–7].

Over recent years, high-frequency ultrasound has emerged as a reliable tool for the diagnosis of peripheral nerve entrapments. Many studies have investigated the diagnostic yields of ultrasound in several peripheral entrapment neuropathies. The most consistent ultrasonographic indicator of nerve compression is the enlargement of the nerve cross-sectional area (CSA) [8–10]. In recent years, multiple studies have provided data on the normal CSAs of several peripheral nerves at their most common entrapment sites [11–15]; however, limited data are available on the normal ultrasonographic reference values of the DBRN at the arcade of Frohse. The existing literature is mainly limited to case reports and small series of patients with PINS/supinator syndrome [16–18]. The normal reference values of the DBRN at this level are important for the ultrasonographic evaluation of patients suspected of having DBRN entrapment in the proximal forearm.

The purpose of this study was to establish normal reference values for the diameters and CSA of the DBRN at the level of the arcade of Frohse in a healthy population. In addition, correlations with age, sex, handedness, and body mass index (BMI) were investigated.

Materials and methods

Study design and setting

This prospective study was conducted from February to October 2017 in the Neuromuscular Diseases Center of

the Physical Medicine and Rehabilitation Department in Rasool-Akram Hospital, which is affiliated to Iran University of Medical Sciences, Tehran. The study was conducted in accordance with the Declaration of Helsinki, and the Regional Ethics Committee of Iran University of Medical Sciences approved its protocol. Informed consent was obtained from all the participants in the study.

Participants

We consecutively recruited 65 healthy volunteers for this study. The inclusion criteria were as follows: (1) aged between 18 and 75 years and (2) having no neuromuscular symptoms, including weakness, tingling, numbness, pain, and cramps in the upper limbs. We excluded patients with a history of significant trauma to the elbow and patients with an underlying medical condition, including diabetes mellitus, hypothyroidism, inflammatory arthritis, chronic renal failure, and morbid obesity, which we defined as a body mass index (BMI) $> 40 \text{ kg/m}^2$. The age, sex, height, weight, and dominant hand of each eligible subject were recorded, and the BMI was calculated.

Ultrasound examination

The ultrasound examinations were performed using a Hitachi ARIETTA V60 (Hitachi Aloka Medical Systems, Tokyo, Japan) ultrasound device with a 5–18 MHz linear transducer. Each patient was positioned in an upright sitting position with the elbows flexed at 20° while resting on an examination table. The forearm was in a neutral position halfway between pronation and supination with the thumb pointing upward. The DBRN was identified using the following method. First, the transducer was placed transversely on the dorsolateral side in the middle of the humerus bone, and the radial nerve was located. Then, the course of the radial nerve was followed distally toward the lateral humeral epicondyle until its bifurcation into superficial and deep branches was identified. The DBRN was then followed distally to the point, where it entered the supinator muscle just beneath the arcade of Frohse. The arcade of Frohse was visualized as a thin hyperechoic curve line at the proximal edge of the most superior part of the supinator muscle using high-frequency ultrasound. The DBRN was typically observed as a hypoechoic oval-shaped structure with a hyperechoic rim located adjacent to the supinator muscle (Fig. 1). The color Doppler mode was used when appropriate to distinguish the nerve from adjacent vessels. The CSA and the anteroposterior (AP) and transverse diameters of DBRN were measured at this level. Figure 2 shows a typical measurement of the CSA of the DBRN using the trace function of the ultrasound device at the level of the arcade of Frohse.

Fig. 1 Ultrasound image, transverse view of the deep branch of the radial nerve (arrow) at the arcade of Frohse. B radius bone, S supinator muscle, M brachioradialis and extensor carpi radialis longus and brevis muscles

All ultrasound examinations were performed by a single expert with 8 years of experience in musculoskeletal ultrasonography. During the ultrasound examination, minimal pressure was applied to avoid the compression and deformation of the DBRN. Moreover, the transducer was maintained perpendicular to the examining nerve to prevent anisotropy. The CSA of the DBRN was measured in transverse section by tracing the internal border of the perineural echogenic rim of the nerve (Fig. 2). During each examination, the CSA value was measured three times, and the mean of the three measurements was considered to be the definitive value. We did not use the magnifying function of the device when measuring the CSA as it was suggested that the magnification of the sonogram might influence the measured CSA values [19].

Statistical analysis

Statistical analysis was performed using the Excel 2010 (Microsoft, Seattle, WA) and SPSS version 18.0 (SPSS, Chicago, IL, USA) statistical software. Descriptive data were reported as mean $\pm$ standard deviation (SD) or number (%) where appropriate. The Shapiro–Wilk test was used to evaluate the normal distribution of the ultrasound-measured variables. Student's *t* test and the Mann–Whitney *U* test were used to compare the data between the groups when appropriate. The reference ranges were calculated as mean $\pm$ 2SD for normally distributed data and

Fig. 2 Typical measurement of the cross-sectional area (CSA) and diameters of the deep branch of the radial nerve (arrow) in transverse view at point of entry to the arcade of Frohse (arrow head). **a** Measurement of the CSA using the trace function. **b** Measurement of the anteroposterior and transverse diameters. B radius bone, S supinator muscle, M brachioradialis and extensor carpi radialis longus and brevis muscles

the 2.5th–97.5th quintile for non-normally distributed data. The upper limit of side-to-side difference was calculated as the mean + 2SD of the absolute values of the side-to-side differences. To examine the correlation between the nerve size and epidemiological factors, including the age, weight, height, and BMI of the subjects, the Pearson's correlation analysis was used. For correlation analysis, the values obtained from the dominant hand were applied. The *p* value of < 0.05 was considered statistically significant.

Data availability

The data sets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Results

Participants

Overall, a total of 65 participants (130 nerves) were enrolled in the study. The subjects consisted of 35 (53.8%) females and 30 (46.2%) males, and all were Caucasians. The mean age was 41.8 ± 11.2 years (range 18–75 years). The

mean height was 165.5 ± 13.8 cm, and the mean BMI was 26.2 ± 3.8 kg/m². The majority of the subjects (90.7%) were right-handed. Table 1 shows the sociodemographic features of the study subjects.

Ultrasound measurements

The Shapiro–Wilk test revealed that the measured CSAs were normally distributed (at a significance level of 0.05). The mean and median values for the CSA of the DBRN were 0.96 ± 0.23 and 0.97 mm², respectively. The reference range (mean $\pm$ 2SD) of the CSA of the DBRN was 0.50–1.42 mm². The mean CSA was 0.98 ± 0.23 mm² in the males and 0.93 ± 0.22 mm² in the females. Although the male subjects tended to have larger CSA values than the females, the difference did not reach the significance threshold ($p = 0.20$). The mean CSA was 0.97 ± 0.23 mm² in the dominant hand and 0.95 ± 0.23 mm² in the non-dominant hand, and the difference was not statistically significant ($p = 0.62$). The mean AP and transverse diameters were 0.83 ± 0.13 and 1.23 ± 0.29 mm, respectively. Table 2 shows the mean, median, 2.5th–97.5th quintiles, and reference ranges of the measured CSAs as well as the diameters of the DBRN.

Correlation with demographic features

Pearson's correlation analysis showed a significant positive correlation between the DBRN CSA measured in the dominant hand and age ($r = 0.41$; $p < 0.001$). On the other hand, no significant correlations were found between the

Table 1 Socio-demographic features of the study subjects

Item	Men ($n = 30$)	Women ($n = 35$)
Age (years) ^a	42.6 ± 10.1	41.1 ± 11.9
Height (cm) ^a	171.4 ± 14.6	161.5 ± 13.0
BMI (kg/m ²) ^a	26.8 ± 4.1	25.6 ± 3.6
Handedness (right/left, n)	27/3	32/3
Occupational status, n (%)		
Unemployed/housewife	5/30 (16.7%)	17/35 (48.5%)
Office clerk	11/30 (36.7%)	16/35 (45.7%)
Laborer	6/30 (20.0%)	0/35 (0.0%)
Salesman	4/30 (13.3%)	2/35 (5.8%)
Retired laborer	4/30 (13.3%)	0/35 (0.0%)

^aData are expressed as mean $\pm$ standard deviation

Table 2 Normal reference values for cross-sectional area and diameters of deep branch of radial nerve

Measured variable	Mean	SD	Median	Percentiles		Reference range	Upper limit of side-to-side difference
				2.5th	97.5th		
CSA (mm ²)							
Total	0.96	0.23	0.97	0.55	1.39	0.50–1.42 ^a	0.35
Dominant arm	0.98	0.24	0.99	0.54	1.39	0.50–1.46 ^a	–
Non-dominant arm	0.93	0.22	0.91	0.56	1.38	0.49–1.37 ^a	–
AP diameter (mm)							
Total	0.83	0.13	0.84	0.58	1.05	0.57–1.09 ^a	0.32
Dominant arm	0.86	0.14	0.90	0.63	1.01	0.58–1.14 ^a	–
Non-dominant arm	0.81	0.12	0.81	0.58	1.06	0.57–1.05 ^a	–
Transverse diameter (mm)							
Total	1.23	0.29	1.07	1.09	1.37	1.09–1.37 ^b	0.41
Dominant arm	1.27	0.32	1.1	1.06	1.48	1.06–1.48 ^b	–
Non-dominant arm	1.19	0.29	1.05	0.99	1.38	0.99–1.38 ^b	–

The upper limit of side-to-side difference is defined as is mean + 2SD of the absolute values of the left and right arms differences

SD standard deviation, CSA cross-sectional area, AP anteroposterior

^aThe reference range is mean $\pm$ 2SD for normally distributed data

^bThe 2.5th–97.5th quintiles for non-normally distributed data

dominant-side CSA and height ($r=0.19$; $p=0.12$) or BMI ($r=0.22$; $p=0.07$).

Discussion

The use of ultrasound for the assessment of peripheral nerve entrapments has increased tremendously over recent years. Ultrasound provides dynamic and real-time visualization of the nerves and the extent of pathological changes. Moreover, ultrasound allows the investigation of any underlying conditions, for instance, ganglion cysts, lipomas, epineural hematomas, or neuroma formation [20]. The most consistent sonographic indicator of entrapment neuropathy in the literature is increased nerve CSA at the entrapment site. It has been suggested that the prolonged compression of the nerve may result in its swelling and enlargement, which, in turn, is recognizable when one observes increased nerve CSA via ultrasonographic examination [21, 22]. Other less commonly reported findings of entrapment neuropathy include nerve flattening, hypoechoic texture, and increased vascularity within the nerve [20–23].

Although the reference values of CSA for most peripheral nerves, including the radial nerve in the arm, have previously been reported [11–15], there is a paucity of data regarding the normal values for the DBRN in the general population. In the present study, we determined the reference values for the CSA of the DBRN at the level of the arcade of Frohse in a healthy population sample. Based on our observations, the reference value (defined as mean $\pm$ 2SD) of the CSA of the DBRN at this level was 0.50–1.42 mm². In the absence of reference values for the normal CSA, the side-to-side CSA comparison was perhaps the most valuable method commonly used in clinical practice. However, it must be appreciated that this method is a vague estimate when the normal side-to-side variations remain undetermined. In the present study, besides reporting the normal values of the CSA, we determined a side-to-side difference of 0.35 mm² as the upper limit of the normal side-to-side CSA difference (Table 2). To the best of our knowledge, this is the largest study evaluating the ultrasonographic reference values of the DBRN in a healthy sample. The values obtained in this study are important for examining DBRN pathologies in the proximal forearm using high-frequency ultrasound.

The existing literature on the ultrasound examination of the DBRN is largely confined to case reports and case series of patients with DBRN entrapment. A case series by Bodner et al. [16] compared the DBRN diameters of four patients with supinator syndrome with the DBRN diameters in ten healthy individuals. The ultrasound study revealed a mean transverse diameter of 2.13 mm and a mean AP diameter of 1.3 mm in healthy individuals. In the patients, considerably larger diameters were observed, with a mean transverse

diameter of 4.2 mm and a mean AP diameter of 3.3 mm. In another series involving 13 patients with PINS, Djurdjevic et al. [17] showed that the mean AP diameter of the DBRN, measured proximal to the arcade of Frohse, was 0.2 cm in patients and 0.11 cm in a healthy control group. The difference between the two groups was statistically significant. In a small study on ten patients with PINS, Kim et al. [18] showed that the AP diameter of the DBRN in the affected arms was significantly larger than that of the DBRN on the contralateral unaffected side. The mean AP diameter of the DBRN in the index study was 1.79 mm on the affected side, whereas the corresponding figure for the unaffected side was 1.02 mm. In our study, the mean AP and transverse diameters of the DBRN at the level of the arcade of Frohse were 0.83 ± 0.13 and 1.23 ± 0.29 mm, respectively, which were comparable to the results obtained for the healthy individuals in the abovementioned case series [16–18]. The slight variations between the studies may be explained by differences in epidemiological characteristics such as age, sex ratio, body weight, and race.

In the present study, the demographic factors, except for age, were not significantly correlated with DBRN size. Age showed a positive correlation with the nerve CSA, whereas height and BMI showed no significant correlations. In addition, there was no significant difference in the nerve size when men and women were compared. A similar finding was noted for handedness: no significant difference was found between the dominant and non-dominant arms. These findings suggested that age should be considered to have an impact on the DBRN CSA, while gender and height were of less concern. Although hardly, any study in the literature explored the associations between DBRN size and epidemiological factors, several authors investigated the relationships between other peripheral nerves and demographic characteristics. A great deal of controversy exists between these studies. The radial nerve CSA measured at the spiral groove, which was the closest example to the DBRN, was shown to have significant correlations with height, weight, and BMI in a number of studies [13, 14], whereas other studies found no similar correlations [15, 16]. Perhaps, age was the demographic factor most consistently reported to be positively correlated with radial nerve CSA in studies [11–13]. The controversy regarding the association between nerve size and demographic factors exists for other upper and lower limb peripheral nerves as well. These discrepancies may be due to variations in the studies' application of anatomic sites for the ultrasound examination of the nerves and differences in the demographic features of the studied samples.

The entrapment of the DBRN at the arcade of Frohse mainly occurs in patients who perform activities that involve repetitive forearm supination and pronation, for instance, laborers, throwing athletes, and musicians. Other less frequent causes include space-occupying lesions such

as ganglion cysts or lipomas [5, 24]. Occasionally, patients with DBRN entrapment may only present with insidious pain over the proximal lateral forearm without objective weakness of the forearm muscles. This presentation of DBRN entrapment is known as RTS and may have a similar clinical manifestation to lateral epicondylitis [24, 25]. The electrodiagnostic study is of limited value in the diagnosis of RTS as it produces very subtle sensory or motor changes [3, 5]. In this situation, ultrasound is particularly helpful in distinguishing between RTS and other etiologies. PINS/supinator syndrome is also on the spectrum of DBRN entrapment at the proximal forearm and is characterized by the slow progressive increase in the weakness of the wrist and the fingers' extensor muscles. This disorder results in the recording of low-amplitude motor action potentials in the extensor muscles and can be easily identified by electrodiagnostic study. Ultrasound can be an appropriate alternative diagnostic tool; however, more studies are needed to compare the diagnostic yields of ultrasound to those of electrodiagnostic studies, where PINS/supinator syndrome is concerned [4–7].

This study has a number of limitations. First, although we included participants with a broad age range (18–75 years) and a relatively even gender ratio to achieve a good estimate of the general population, nearly, all the participants were Caucasian. Therefore, the generalizability of our results to other ethnicities is not known. Moreover, our results cannot be extrapolated to the pediatric age group. Second, this study did not include individuals with underlying medical conditions, particularly, morbid obesity, diabetes mellitus, and hypothyroidism. It has been suggested that the CSAs of the peripheral nerves in patients with these conditions may be larger than those in healthy controls, even in the absence of neurological symptoms [22]. Therefore, caution should be exercised when generalizing our results to patients with underlying medical conditions.

In conclusion, in this study, we determined the ultrasound reference values for the DBRN at the level of the arcade of Frohse in asymptomatic individuals. The measurements obtained will be valuable for studying DBRN pathologies using high-frequency ultrasound. Our observations suggested the importance of considering age in the assessment of DBRN CSA. Further studies involving other ethnicities and populations are warranted.

Compliance with ethical standards

Funding None.

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the insti-

tutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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